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Internet of Things applied to Aquifer Monitoring Systems: A survey.

Ariza-Colpas Paola Patricia[a,*], Sanchez-Moreno, Hernando Alberto[e] and Pineres-Melo Marlon Alberto[b], Morales-Ortega Roberto Cesar[a], Ayala-Mantilla, Cristian Eduardo[c], Villate-Daza, Diego Andrés[c], De-la Hoz-Franco Emiro[a], Collazos-Morales Carlos Andrés[d].

[a]*Universidad de la Costa, CUC. Street. 58 # 55 - 66 Barranquilla – Colombia*
[b] *Universidad del Norte. Kilometer. 5 Via Puerto Colombia. Barranquilla – Colombia.*
[c]*ARC Barranquilla Naval School of Subofficials. Carrer. 82 #58-164 Barranquilla, Colombia*
[d]*Universidad Manuela Beltran. Career. 1 # 60 - 00 Bogotá – Colombia.*
[e]*Universidad Simón Bolívar. Street. 58 # 55-132.Barranquilla – Colombia.*

Abstract

The interaction between the oceanic and continental basins has been of general interest among the scientific community of multiple disciplines, from the physical perspective of how the interaction of fresh and salt waters mutually modulate their hydrodynamic behavior, and how this in turn determines the transport of sediments, nutrients and other tracers, in addition to inducing changes in the morphodynamics of the river and / or coastal-oceanic zone. Due to the importance of technology for the prevention of different environmental phenomena, this article aims to show the systematic review of the literature about different applications that allow software and hardware interaction to support decision making in the sense of aquifers.

Keywords: Wireless System, Aquifer Monitoring Systems, Internet of Things.

* Corresponding author. Tel.: +57 - 3002287498; Fax: +355 22 66 999
E-mail address: pariza1@cuc.edu.co

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1. Introduction

The mouth of the Magdalena River in particular is the most important multipurpose estuarine system in the country. There the urban and industrial development of the city of Barranquilla (the largest in the Colombian Caribbean) coexists, with large-scale river navigation and the collection of water for human consumption from much of the department of the Atlantic, in addition to advanced initiatives for the Renewable energy generation from salinity gradients [1,2].

The mouth of the Magdalena River, being Colombia's most important estuarine system and having global relevance [3-5], is also the system that has aroused the most interest in its research. As can be seen in the conceptual framework, in recent years important initiatives have been carried out to sample this mouth and generate a basic knowledge about its dynamics. However, the limitations in the capabilities of instrumentation, transmission, storage and data access protocols have not allowed the study of circulation, stratification, mixing and turbulence processes in the Magdalena River estuary to be approached in greater detail. This is because the analysis of the aforementioned processes requires observations at longer time scales (from the order of months to years) and with greater spatial coverage (at the scale of the entire estuarine system).

The stratification and mixing processes due to the intrusion of the salt wedge are the most relevant in the dynamics of the mouth of the Magdalena River [4, 6-8]. This intrusion influences not only the temporal variability and spatial gradients of water salinity and temperature, but also changes in turbulence and circulation, which in turn determine changes in sediment accumulation and / or transport [5, 9,10,18]. This migration of the salt wedge produces cyclically effects on the quality of water for human consumption and navigation of great draft, as well as it could have a negative effect on the exploitation of energy from salinity gradient, which is in principle feasible at this mouth [2,5].

This article is the result of the execution process of the project "Implementation of a wireless system of conductivity temperature sensors and support pressure for the identification of the salt wedge and its impact on the maritime safety of the Magdalena River estuary" funded by Colciencias alliance with - Ministry of Defense of Colombia and aims to show the literary revision that took place for the implementation of the system in the estuary of the Magdalena River. This article first shows the materials and methods used for the analysis of the state of the art with scientometric variables resulting from the review. Second, some important works related to the subject are explained. Finally, the discussion of the results and the conclusions resulting from the review of the literature.

2. Conceptual Information

Due to the availability of fresh water and at the same time the access to the sea offered by the areas of influence of the mouths, these systems have always been sites of human settlements where activities of urban and industrial development, port trade, navigation, agriculture coexist , tourism, fishing, among others. The joint and optimal development of all these activities require a thorough knowledge of the physical processes that occur in these systems and their involvement by (and over) anthropic activities. The mouth of the Magdalena River is the development stage of the most important city and port area of the Colombian Caribbean. In the last 20 km of the river, the main industrial and port areas of the city of Barranquilla-Colombia coexist and the collection of water for human consumption of Barranquilla and the surrounding municipalities takes place. Without a doubt, the sustainable economic growth of the city of Barranquilla, the Caribbean region and Colombia in general, require a holistic understanding of the physical processes that develop in this estuary. This without forgetting that the mouth is a natural system of great importance for the sedimentary balance and the contribution of nutrients to the Colombian Caribbean coast [10,19] and therefore its uses must interact in a manner compatible with the ecosystem services it provides.

The main physical process that governs the dynamics of the mouth of the Magdalena River and therefore the one that most influences its multiple uses is the intrusion of the salt wedge. This phenomenon presents a marked seasonal and inter-annual variability associated with the latitudinal migration of the intertropical convergence zone [6,20] and the occurrence of El Niño / La Niña events [7,21]. Since the zone of maximum turbidity (where there is greater sedimentation), migrates along the estuary depending on the position of the salt wedge [4,6,8], knowledge of the

spatio-temporal patterns of salinity and temperature will allow predicting the sites where the highest sedimentation rates will occur in the estuary, which increases the decision-making capacity for navigation. At the same time, the analysis of the salt wedge will allow defining the scenarios under which salinization can occur in the areas of location of the water intakes for human consumption.

The interaction between the oceanic and continental basins has been of general interest among the scientific community of multiple disciplines, from the physical perspective of how the interaction of fresh and salt waters mutually modulate their hydrodynamic behavior, and how this in turn determines the transport of sediments, nutrients and other tracers, in addition to inducing changes in the morphodynamics of the river and / or coastal-oceanic zone [1, 3,9,11-13]. Freshwater discharges from the Magdalena River show high variability during the year, from maximum multi-year average flows at Calamar station close to 10049 m3 / s for the month of November to minimums of 4175 m3 / s during the month of March and a sediment transport in average suspension of 144 x 106 t / year [8,22]. The tide in this area of the Caribbean has a mixed micro tidal regime that reaches amplitudes between 0.48 m and 0.64 meters between periods of dead and alive tides [14,23].

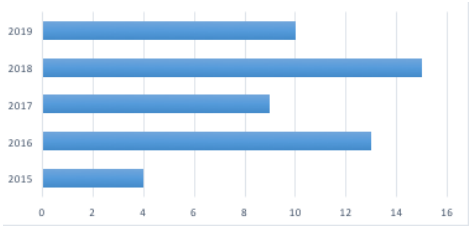
The interaction of the discharge of the Magdalena River with the coastal-oceanic waters of the Caribbean Sea defines an estuarine zone that can extend up to km 20 inland from the river [7,24], where hydrodynamic processes are regulated spatially and temporarily by the volume of Fresh water discharged by the river, the tide, the waves, the migration of the intertropical convergence zone (which modifies the pattern and magnitude of winds over the Caribbean basin and precipitation patterns in the river basin) [15] and the natural and anthropogenic changes in the basin and in the geomorphological configuration of the river discharge zone in the Colombian Caribbean Sea [5]. The winds that force surface currents (coastal and oceanic) record their highest speeds in the months of December and January in a range between 8 and 12 m / s, and the lowest speeds occur between the months of September to November with values that they range between 2 and 6 m / s [16]. The wind, apart from modifying the coastal and oceanic currents, defines the extent of the sediment boom and limits their transport processes, which are also modified by the Panama - Colombia countercurrent which near the mouth of the river Magdalena reaches zonal speeds between 0.1 and 0.3 m / s [17].

Previous studies based on field measurements (largely carried out by the research team presenting this proposal) have allowed us to verify that the Magdalena River estuary is highly stratified vertically [4,7,9], with a saline wedge entering to the estuary seasonally at the time of low flows (December-April) and is expelled from the estuary by increasing the flows the rest of the year [7]. It has also been preliminary identified that the extent of saline intrusion is strongly related to the occurrence of the El Niño / La Niña phenomenon, with the greatest saline intrusions occurring during the warm phase of this phenomenon (El Niño) [7]. It has been found that the Magdalena River is one of the river systems with the highest discharge of sediments to the sea and to its mouth in the world [14]. In times of saline intrusion, it is when more sedimentation occurs at the mouth, mainly due to suppression of the shear stresses at the bottom [4]. The area where there is greater deposition of the sediments that the river brings is precisely in the sector of maximum intrusion of the salt wedge. This is due to the abrupt decrease in the near-bottom flow rate [4] and possibly due to sediment flocculation.

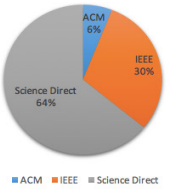
3. Materials, Methods and Scientometric Analysis

For the development of this systematic review, IEEE, ACM, Science Direct databases were consulted. Taking the following reference keywords: "salt wedge", "estuaries", "salinity sensor", "coastal monitoring network". After an exhaustive filter, 53 directly related papers could be identified, of which the meta-analytical variables shown in the graphs below are shown. Taking into account the systematic review of the literature, the meta-analytical results are shown. In 2015, 4 articles related to the keywords were published. In 2016, they were published with 13 articles. In 2017, 9 articles were published. In 2018, 15 articles were published, this year being the one with the highest number of publications and up to the search date, 10 articles were published in 2019, see Figure 1 (a). As a result of the review, it can be noted that the majority of articles have been published in the Science Direct database 64%, then the most published database in this area of IEEE knowledge with 30% and finally the database ACM 6%, see Figure 1 (b).

Most of the publications are in Q1 quartile with 32 articles, then Q2 articles with 10 articles, then articles in third quartile 7 and finally 5 works in Q4, see Figure 2 (a). In the same way, the countries that publish the most in this line of work are the Netherlands, then the United States, followed by the United Kingdom. Subsequently, the following countries, see Figure 2 (b).

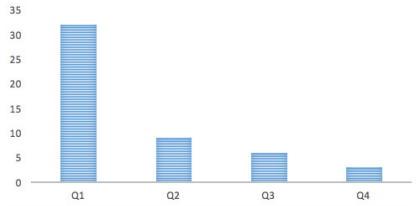


(a)

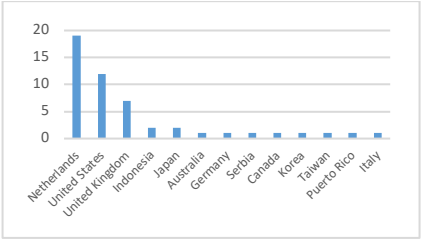


(b)

Fig. 1. (a) Publication´s Year, (b) Data Base Search Result.



(a)



(b)

Fig. 2. (a) Publication Quartil's Distribution, (b) Publication by Country.

Analyzing the countries of the first authors, it can be highlighted that most of the works have been published by authors of Chinese nationality, followed by authors from the United States and the others shown in the Figure 3.

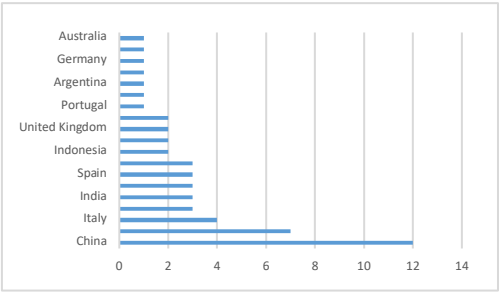


Fig. 3. Publication by First Author ´Country.

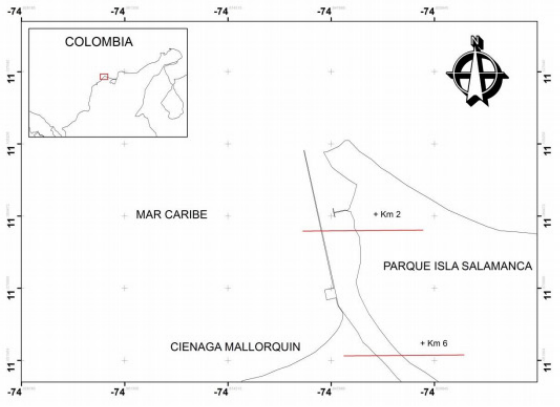
4. Work Proposed.

Based on the systematic review of the literature served to propose a system of analysis of variables in aquifers in the department of Atlántico, on the final sector that gives the mouth of the Magdalena River on the Caribbean coast, in order to measure the variables of temperature, conductivity and depth as the basis for the analysis of the saline wedge

phenomenon that predominantly affects the dynamics of the daily action of the navigable channel between the following coordinates.

Table 1. Coordinates study area

Latitude	Length
-74,819661 W	11,128976 N
-74,921967 W	11,128557 N
-74,921548 W	11,056439 N
-74,813092 W	11,056020 N



The proposed architecture consists of 2 buoys located at kilometers 2 and 6 respectively, of the Magdalena River in Colombia. These specific points have been defined taking into account the following variables: accessibility for maintenance, installation costs, data coverage in relation to spatial geographical conditions and equipment safety, see Figure 4.

The system will be connected to a central communications base where the data is stored to later identify the different variations of these variables in order to support the maritime safety of the Magdalena River.

Fig. 4. Location of the study area

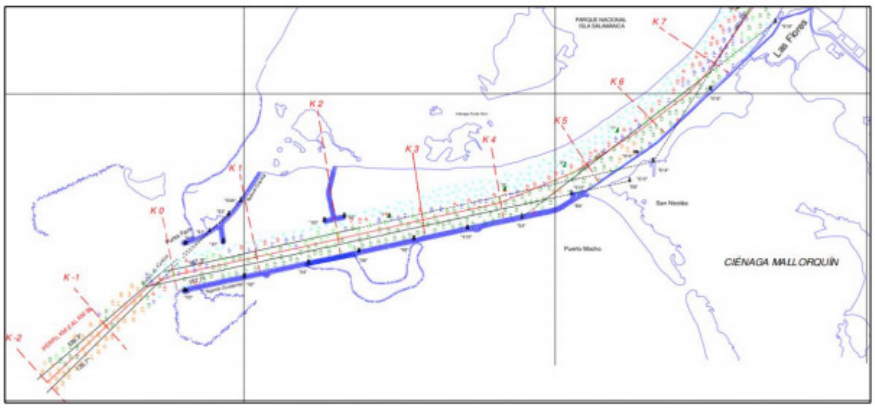


Fig. 5. Final bathymetric sheet segmented by kilometers with navigation aids Source CIOH-SEMAB

In Figure 4, you can clearly identify where the 6 kilometers and buoys reach possibly they can be used as sensor installation platforms, buoy 1 is the closest to the mouth so they would be considered first hand as the one data can be obtained with a higher resolution. In order to give a greater range of action to the census of the equipment, the buoy 7 that is close to Kilometer 6 was also chosen.

Conclusions.

Some of the advantages of these systems are the large spatial and temporal resolution of the monitored parameters, and in addition, the deployment of such a network requires a lower investment in both cost and time, compared to classic solutions such as those used in the Oceanographic observatories in which resources with higher benefits are used (deep water buoys, AUV's, gliders, Lagrangian buoys, etc.). The knowledge of the spatio-temporal patterns of salinity and temperature will allow predicting the sites where the highest sedimentation rates will occur in the estuary, which increases the decision-making capacity for navigation. At the same time, the analysis of the salt wedge will allow defining the scenarios under which salinization can occur in the areas of location of the water intakes for human consumption.

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